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Summary of WG4
"Lifetime, mixing and weak mixing phase in charm and beauty, including direct determination of V_{tx}"

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We present the summary of the Working Group on lifetimes, mixing and weak mixing phases in charm and beauty mesons at the CKM 2010 workshop. In the past year or so good progress was achieved on both experimental and theoretical sides. While this yields improvement in our understanding of neutral meson mixing, further work is necessary to achieve the highest possible precision in order to investigate current hints for deviations between experiment and standard model predictions. With the recent LHC startup we see bright prospects for the near term future for huge improvements.

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1 Introduction

Mixing of neutral mesons provided an important tool for the development of the standard model and continues to be important to test it. It also provides crucial information in searches for physics beyond the standard model and constraining models of new physics. In this paper we concentrate on the mixing of neutral mesons containing b or c quarks. In the bottom and charm sectors, improvements on both experiment and theory sides since the previous CKM workshop brought advances in the quest for new physics. In addition with the start of the LHC operation we are entering a new era in which tests with unprecedented precision will become reality.

In this paper we summarise 13 contributions to the working group on "Lifetime, mixing and weak mixing phase in charm and beauty" together with lively discussions triggered by those contributions. They covered all aspects of mixing of b and c mesons as well as prospects for the future improvement of our knowledge of mixing.

2 B mixing

2.1 Mixing formalism

We start with the description of mixing of B_q mesons ($q = d, s$), which is governed by the Schrödinger-like equation

$$i\frac{d}{dt}\begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix} = \left(\hat{M}^q - \frac{i}{2}\hat{\Gamma}^q\right)\begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix}, \tag{1}$$

where $\hat{M}^q$ and $\hat{\Gamma}^q$ are mass and decay rate 2×2 hermitian matrices. The box diagrams for B_q mixing give rise to off-diagonal elements M_{12}^q and Γ_{12}^q in the mass matrix $\hat{M}^q$ and the decay rate matrix $\hat{\Gamma}^q$. Diagonalisation of $\hat{M}^q$ and $\hat{\Gamma}^q$ yields mass eigenstates

$$B_{q,H} = p\, B_q - q\, \bar{B}_q, \tag{2}$$

$$B_{q,L} = p\, B_q + q\, \bar{B}_q, \tag{3}$$

with p and q being complex numbers satisfying $|p|^2 + |q|^2 = 1$. The off-diagonal elements of the mass and decay matrices can be related to three measurable observables: the mass difference

$$\Delta M_q := M_H^q - M_L^q = 2|M_{12}^q|\left(1 + \frac{1}{8}\frac{|\Gamma_{12}^q|^2}{|M_{12}^q|^2}\sin^2\phi_q + ...\right), \tag{4}$$

the decay width difference

$$\Delta\Gamma_q := \Gamma_L^q - \Gamma_H^q = 2|\Gamma_{12}^q|\cos\phi_q\left(1 - \frac{1}{8}\frac{|\Gamma_{12}^q|^2}{|M_{12}^q|^2}\sin^2\phi_q + ...\right) \tag{5}$$

and the CP asymmetry in flavour specific decays

$$a^q_{fs} \;=\; \mathrm{Im}\frac{\Gamma^q_{12}}{M^q_{12}} + \mathcal{O}\left(\frac{\Gamma^q_{12}}{M^q_{12}}\right)^2 = \frac{\Delta\Gamma_q}{\Delta M_q}\tan\phi_q + \mathcal{O}\left(\frac{\Gamma^q_{12}}{M^q_{12}}\right)^2, \tag{6}$$

where $\phi_q = \arg(-M^q_{12}/\Gamma^q_{12})$.

2.2 Standard model predictions for the mixing quantities

In the standard model the off-diagonal elements M^q_{12} are given by

$$M^q_{12} \;=\; \frac{G_F^2}{12\pi^2}(V^*_{tq}V_{tb})^2 M_W^2 S_0(x_t) B_{B_q} f^2_{B_q} M_{B_q}\hat{\eta}_B\,. \tag{7}$$

Γ^d_{12} is negligibly small compared to the current experimental precision. On the contrary Γ^s_{12} is large enough to be important. The standard model predicts for $\Delta\Gamma_s$ [1]

$$\Delta\Gamma_s \;=\; \left(\frac{f_{B_s}}{240\,\mathrm{MeV}}\right)^2 \left[0.105B + 0.024\tilde{B}'_S - 0.027B_R\right], \tag{8}$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} \;=\; \left[46.2 \quad + 10.6\frac{\tilde{B}'_S}{B} - 11.9\frac{B_R}{B}\right] \times 10^{-4}. \tag{9}$$

In these expressions, V_{tq} and V_{tb} are CKM matrix elements, M_W and M_{B_q} are masses of W boson and B_q meson, $S_0(x_t)$ and $\hat{\eta}_B$ include the perturbative part and finally B_{B_q}, f_{B_q}, B, B'_S and B_R contain the non-perturbative part of the amplitude. The CKM matrix elements together with the non-perturbative contribution are currently the two dominant factors limiting the precision of the standard model predictions. The non-perturbative matrix elements are evaluated using non-perturbative methods like lattice QCD, which made significant progress over the past few years [2]. As an example the precision on f_{B_d} and f_{B_s} is now in the region of 4–8% with further prospects for improvements. The reassuring fact of those calculations is that results of unquenched calculations from several collaborations are now available and in good agreement. In addition, different collaborations use different formulations for heavy and light quarks, which adds to the confidence in the values of non-perturbative matrix elements and their uncertainties. More details are discussed by N. Garron in these proceedings [3], see also [4] and references therein.

One point worth noting is that for B_d and B_s mesons Γ^s_{12}/M^s_{12} is about 5×10^{-3} and therefore in the expressions presented here one can safely neglect terms containing $(\Gamma^q_{12}/M^q_{12})^2$. Plugging in the latest values for all input parameters, the standard model predictions are [5]

$$\Delta M_s \;=\; (17.3 \pm 2.6)\ \mathrm{ps}^{-1}, \tag{10}$$

$$
\begin{aligned}
\frac{\Delta\Gamma_s}{\Gamma_s} &= 0.137 \pm 0.027, &(11)\\
a_{fs}^s &= (1.9 \pm 0.3) \times 10^{-5}, &(12)\\
\phi_s &= 0.22^\circ \pm 0.06^\circ, &(13)\\
\frac{\Delta\Gamma_d}{\Gamma_d} &= (4.2 \pm 0.8) \times 10^{-3}, &(14)\\
a_{fs}^d &= -(4.1 \pm 0.6) \times 10^{-4}, &(15)\\
\phi_d &= -4.3^\circ \pm 1.4^\circ, &(16)\\
A_{fs}^b &= 0.494 a_{sl}^s + 0.506 a_{sl}^d = (-2.0 \pm 0.3) \times 10^{-4}. &(17)
\end{aligned}
$$

Here A_{fs}^b is the flavour-specific asymmetry averaged over B^0 and B_s where the two weights are given by the product of the fragmentation fraction of b-quarks into given hadrons and the time integrated mixing probability [6]. Experimentally it can be accessed by measuring the asymmetry in same-sign dileptons at hadron colliders to which we will turn later.

It is interesting to note that due to the progress in the lattice determination of the decay constants, currently the dominant uncertainty in Γ_{12} stems from the non-perperturbative matrix elements of power-suppressed four-quark operators [5].

2.3 Testing the HQE through lifetimes

The above predictions rely on the Heavy Quark Expansion (HQE), which itself needs to be tested. One of the most accurate tests we have these days uses lifetime ratios of the b hadrons. The lifetimes are governed by the $b \to c$ tree level transition and thus expected to be completely dominated by the standard model. Thus if a discrepancy between theory and experiment exists, it is a clear signal of issues with the HQE rather than a sign of new physics. In the ratio of lifetimes the overall m_b^5-dependence as well as several hadronic uncertainties cancel. Currently the accuracy of the theory predictions is strongly limited by the lack of up-to-date values for the bag parameters of the arising non-perturbative four-quark matrix elements. Using the ten year old values of Ref. [7] one obtains [5]

$$
\begin{aligned}
\frac{\tau(B_s)}{\tau(B_d)} - 1 &\in [-4 \times 10^{-3}; 0], &(18)\\
\frac{\tau(B^+)}{\tau(B_d)} - 1 &= 0.044 \pm 0.024. &(19)
\end{aligned}
$$

Here the $\tau(B_s)$ is defined as inverse of the mean decay width of the two mass eigenstates. For the error estimates all numerical input parameters were varied within their one sigma range and the individual uncertainties were finally added quadratically. We emphasize again that the numerical value of the lifetime predictions depends strongly

on the values of the color-suppressed four-quark matrix elements, that are hardly known, see [5] for more details. A typical number quoted for the Λ_b lifetime is e.g. [8]

$$\frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.88 \pm 0.05. \tag{20}$$

It is worth to note that the theory prediction for Λ_b is not as complete as for the other two ratios. Currently we still lack the full NLO-QCD calculation and the input from lattice QCD.

Despite that B^0 and B^+ lifetimes were known at subpercent precision from B-factories, CDF recently joined the game and provided new measurements, which match the precision of the B-factories and are consistent with them [9]. The world average lifetimes are $\tau(B^+) = 1.638 \pm 0.011\,\mathrm{ps}$ and $\tau(B^0) = 1.525 \pm 0.009\,\mathrm{ps}$ [10]. This translates to the ratio $\tau(B^+)/\tau(B^0) = 1.074 \pm 0.010$ [10] which is consistent with theory. The measurements of the B_s lifetimes are more difficult due to the non-zero decay width difference. Best measurements come from the angular analysis of $B_s \to J/\psi\phi$ decays where one can measure $\tau(B_s) = 2/(\Gamma_{qH} + \Gamma_{qL})$. The latest results are $\tau(B_s) = 1.529 \pm 0.025 \pm 0.012$ ps from CDF [11] and $\tau(B_s) = 1.45 \pm 0.04 \pm 0.01\,\mathrm{ps}$ from DØ [12]. Our average of those two measurements yields the lifetime ratio $\tau(B_s)/\tau(B^0) - 1 = (-13.1 \pm 5.9) \times 10^{-3}$, again consistent with theory expectation. The Λ_b lifetime is the most problematic part. On one hand the theory prediction is incomplete. On the other hand the experimental results are not in good agreement. The latest two measurements from CDF which are of highest precision yield results which are well above all other measurements. In numbers, CDF measures $\tau(\Lambda_b) = 1.401 \pm 0.046 \pm 0.035$ ps using the $\Lambda_b \to \Lambda_c\pi$ decay and $\tau(\Lambda_b) = 1.537 \pm 0.045 \pm 0.014$ ps using the $\Lambda_b \to J/\psi\Lambda$ decay [9]. Performing a naive average which neglects correlated uncertainties the lifetime from CDF is $\tau(\Lambda_b) = 1.483 \pm 0.037\,\mathrm{ps}$ while the world average excluding the CDF measurements is $\tau(\Lambda_b) = 1.230 \pm 0.074\,\mathrm{ps}$. Also using the two most precise measurements the ratio of Λ_b to B^0 lifetimes is above the prediction, but given that the theory prediction is incomplete and the discrepancies on the experimental side we should not draw any conclusion about the validity of HQE from that yet.

We complete this section by discussing the decay width difference in the B_s system. Both CDF and DØ measure together with the mean B_s lifetime also $\Delta\Gamma_s$. Omitting details discussed elsewhere in these proceedings, they obtain values of $\Delta\Gamma_s = 0.075 \pm 0.035 \pm 0.01\,\mathrm{ps}^{-1}$ (CDF) [11] and $\Delta\Gamma_s = 0.15 \pm 0.06 \pm 0.01\,\mathrm{ps}^{-1}$ (DØ) [12]. While both have central values in the region of theory expectations, the precision is not yet sufficient to firmly establish a non-zero decay width difference nor to obtain a strong test of theory. Contrary to the B_s system in B^0 system the decay width difference does not get lot of attention. As pointed out by T. Gershon experiments should turn back to question of the decay width difference in the B^0 system [13].

3 Direct determination of $\mathbf{V_{td}}$, $\mathbf{V_{ts}}$ and $\mathbf{V_{tb}}$

The elements of the CKM matrix are free parameters of the standard model and as such they need to be extracted from experiments. Ideally one would like to have a determination which is independent of assumptions on the underlying physics. In practice it is non-trivial to determine V_{tx} elements with sufficient precision without some assumptions.

In the context of the standard model the main feature of the CKM matrix is its unitarity, which reduces the number of free parameters to four. Using the absolute values of the elements in first two rows supplemented by the single phase γ measured in $B \to D^{(*)}K$ decays with the assumption of unitarity it is possible to extract V_{tx} elements from tree level processes with astonishing precision. Further improvements in precision can be achieved by including loop level processes into the determination. A current analysis using only tree level quantities yields [14]

$$
\begin{aligned}
V_{td} &= (0.00896 \pm\ 0.0006\ \ \&\ \ 0.01081 \pm 0.0006) \times e^{i(-22.9\pm 1.4)^\circ}, && (21)\\
V_{ts} &= -0.03979 \pm 0.00052 \times e^{i(-1.163\pm 0.084)^\circ}, && (22)\\
V_{tb} &= 0.99916 \pm 1.8 \times 10^{-5}. && (23)
\end{aligned}
$$

The two values of V_{td} stem from two independent values of the CKM angle γ used in the fit. Once we drop the requirement of unitarity, the situation is more difficult as the well measured elements from the first two rows do not provide strong constraints anymore. As an example fourth generation or models with additional vector-like quarks are often discussed. In the first case, the mixing matrix becomes a 4×4 matrix while in the second case it becomes a 4×3 matrix. In such cases all elements can get modified, but with the high precision direct measurements of the first two rows, most of the impact is in the V_{tx} elements. In both cases large modifications of V_{ts} and V_{td} are possible. For additional discussion we refer the reader to the discussion by Rohrwild [15] or the original papers, e.g. Ref. [16].

Experimentally we can access the V_{tx} elements without imposing an unitarity constraint in top quark physics. Both $t\bar{t}$ pair production as well as electroweak single top quark production can be used. The V_{tx} elements enter those processes both at the production as well as at the decay. The Tevatron experiments used both production mechanisms. When analysing the $t\bar{t}$ pair production sample, they split the data according to the number of b-tagged jets. In the fit they extract in addition to the cross section itself also $\mathcal{R}_b = |V_{tb}|^2/(|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2)$. The DØ analysis yields $\mathcal{R}_b = 0.97^{+0.09}_{-0.08}$ including both statistical and systematic uncertainties [17]. Using the 95% CL limit $\mathcal{R}_b > 0.79$ from [17] leads to the constraint

$$|V_{td}|^2 + |V_{ts}|^2 < 0.263 \cdot |V_{tb}|^2\,.$$

The single-top cross-section is measured by both CDF [18] and DØ [19] and their combined result is $\sigma = (2.76^{+0.58}_{-0.47})\,\mu$b. Comparison of this result with cross-section

predictions which use $|V_{tb}| = 1$ yields $|V_{tb}| = 0.88 \pm 0.07$. Clearly the precision of those determinations is not very high. Moreover the Tevatron experiments are already close to being systematically limited and therefore, despite the much larger statistics expected at LHC, it will require non-trivial work to substantially improve those results. For more a detailed discussion of the experimental aspects see Ref. [20].

4 New physics in B meson mixing

4.1 Model independent analysis

An important thread for the current studies of B meson mixing is the quest for new physics beyond the standard model. Being a loop induced process, it is a well suited laboratory for such searches. For the B_s system new physics can be parametrised as [1]

$$\Gamma_{12,s} = \Gamma_{12,s}^{\text{SM}}\,, \qquad M_{12,s} = M_{12,s}^{\text{SM}} \cdot \Delta_s\,; \quad \Delta_s = |\Delta_s| e^{i\phi_s^\Delta}. \tag{24}$$

It should be noted that in this parametrisation new physics does not affect Γ_{12}. While this is not strictly correct, for most of the models typically discussed the space for new physics to affect Γ_{12} is very limited. This limitation comes from the lifetime of B_s mesons, which would be affected by such a contribution. The general agreement is that a new physics contribution to Γ_{12} is well below the hadronic uncertainties and is thus usually omitted. With this parametrisation the observables become

$$\Delta M_s = 2|M_{12,s}^{\text{SM}}| \cdot |\Delta_s|, \tag{25}$$

$$\Delta \Gamma_s = 2|\Gamma_{12,s}| \cdot \cos\left(\phi_s^{\text{SM}} + \phi_s^\Delta\right), \tag{26}$$

$$a_{fs}^s = \frac{|\Gamma_{12,s}|}{|M_{12,s}^{\text{SM}}|} \cdot \frac{\sin\left(\phi_s^{\text{SM}} + \phi_s^\Delta\right)}{|\Delta_s|}, \tag{27}$$

$$\phi_s^{J/\psi\phi} = -2\beta_s + \phi_s^\Delta + \delta_{\text{Peng.}}^{\text{SM}} + \delta_{\text{Peng.}}^{\text{NP}}. \tag{28}$$

The quantity $\phi_s^{J/\psi\phi}$ is the CP violating phase measured in $B_s \to J/\psi\phi$ decays with $\beta_s = \arg\left(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*\right)$. It can receive the standard model contribution from the tree level decay diagram with interference with and without mixing ($-2\beta_s$), the contribution from new physics in the box diagram (ϕ_s^Δ) and the contribution from penguin decay diagrams both from the standard model and new physics, see [21] for a discussion of the standard model penguins in the case of B_d decays.

4.2 New physics in $\mathrm{B_d}$ mixing

Let us first discuss the B_d^0 system, which currently shows an about 2.5σ discrepancy between the CP violation in $B_d^0 \to J/\psi K_S$ measured by the experiments and a one

determined from the unitarity triangle fits which omits it on input [22, 23, 24, 25]. The final measurement from the BABAR experiment yields $\sin(2\beta) = 0.687 \pm 0.028 \pm 0.012$ [26]. The most recent measurement of the Belle experiment gives $\sin(2\beta) = 0.650 \pm 0.029 \pm 0.018$ [27]. Belle still analyses its full dataset with improvements to the software, which offers improvements better than just scaling with statistics. With the final dataset they expect to achieve a statistical uncertainty on $\sin(2\beta)$ of 0.024. The value extracted by the UTFit collaboration when omitting $\sin(2\beta)$ from the fit is 0.771 ± 0.036 which is about 2.6σ away from the world average of measurements [14]. A similar conclusion holds also for other unitarity triangle fits [23, 24]. One of the questions is whether this discrepancy is an early indication of new physics or whether the penguin contributions which are typically neglected can account for this discrepancy. This question was discussed in the presentation by M. Ciuchini [21] who presented several ways of assessing the effects of the penguin pollution. From his analysis it seems unlikely that a significant part of the discrepancy would be due to neglected penguin pollution. With the estimates which are possible with current data, the discrepancy can be decreased to the level of 2.3σ.

4.3 New physics in the $\mathrm{B_s}$ system

The most important measurement these days in terms of the search for new physics in B_s mixing is the measurement of the CP violating phase $\phi_s^{J/\psi\phi}$. Both Tevatron experiments performed this measurement at the end of 2007 and early 2008 for the first time [28, 29]. At that time both experiments had result where the consistency between data and the standard model was about 1.5σ, which caused quite some excitement. In 2010 both experiments updated their analyses, CDF using 5.2 fb^{-1} [11] and DØ using 6.1 fb^{-1} [12]. The extracted confidence regions in $\Delta\Gamma_s$-$\phi_s^{J/\psi\phi}$ plane are shown in Fig. 1. Projecting down the CDF result yields $\phi^{J/\psi\phi} \in [-1.04, -0.04] \cup [-3.10, -2.16]$ rad at 68%CL. The DØ experiment extracts a value $\phi^{J/\psi\phi} = -0.76^{+0.38}_{-0.36}(\mathrm{stat}) \pm 0.02(\mathrm{syst})$ rad. It should be noted that both experiments now see better agreement between the standard model and their data, but large new physics effects cannot be excluded. While the Tevatron experiments still collect data and expect about a factor of 2 more by the end of 2011, the future of this measurement is at the LHCb experiment. With only $600\,\mathrm{nb}^{-1}$ they could extract first $B_s \to J/\psi\phi$ signal. While the simulation does not yet fully agree with the early data, none of the discrepancies significantly limits the capability of the LHCb experiment to perform the analysis. The Monte Carlo projections shown in Fig. 1 indicate that LHCb can be competitive with data taken in 2011 [30], but one should be a little cautious as the uncertainty depends on the values of other physics parameters like $\Delta\Gamma_s$.

The second measurement sensitive to new physics in the $B_{(s)}$ mixing phase is the measurement of flavour-specific asymmetries a^q_{fs}. Despite the fact that these asymmetries are expected to be small even in the case of large new physics effects,

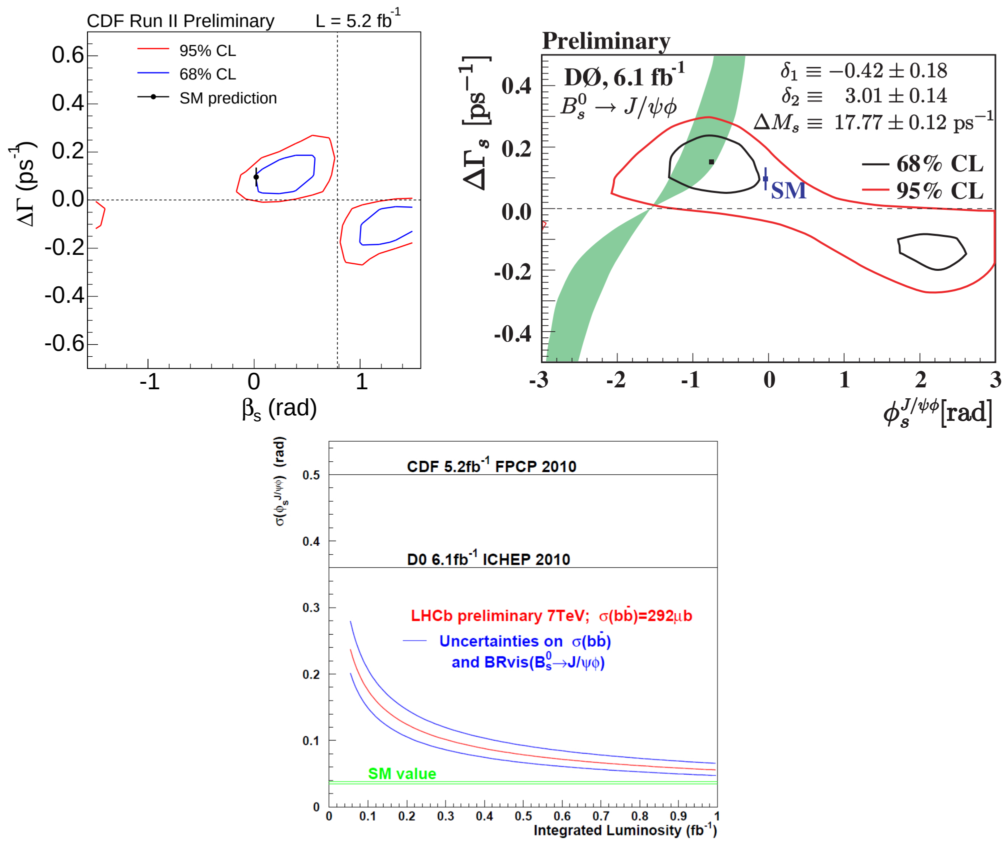

Figure 1: Confidence regions in $\Delta\Gamma_s$-($\phi_s^{J/\psi\phi} \equiv -2\beta_s$) plane measured in $B_s \to J/\psi\phi$ decays at CDF (left left) and DØ (top right). Projection of expected uncertainty on $\phi_s^{J/\psi\phi}$ at the LHCb experiment as a function of integrated luminosity for running at $\sqrt{s} = 7\,\mathrm{TeV}$ (bottom).

the DØ experiment managed to perform this challenging measurement by measuring the asymmetry between same sign dimuons in b events. They measure A_{sl}^b which is a mixture of a_{fs} for B^0 and B_s to be $(-95.7 \pm 25.1 \pm 14.6) \times 10^{-4}$ [12, 31], which is about 3.2σ away from the standard model expectation of $(-2.3^{+0.5}_{-0.6}) \times 10^{-4}$ [1]. The updated SM prediction of A_{sl}^b announced at the CKM workshop [5] has no visible effect on the significance of the discrepancy. If this stands, this is probably the strongest indication of new physics in a particle physics experiment we have. While no other measurements which would be competitive to the DØ one are available up to now, LHCb presented an interesting idea of a complementary measurement. The plan is to measure the semileptonic asymmetry separately for B_d^0 and B_s, using the same final state $KK\pi l\nu$. This way, the detector asymmetry cancels in the difference. It opens up the possibility for a precise measurement which would be complementary to the

DØ measurement. Combination of the two measurements would allow to disentangle contributions from B_s and B^0 with high precision. With LHCb taking data and the Tevatron experiments having a large sample already available we should see progress very soon.

A combined fit of observables both in the B_d^0 as well as in the B_s-system tends to favor new physics acting in both systems, see e.g. [5, 22].

5 Charm sector

The mixing of charm mesons provides information complementary to B mesons or kaon mixing. The reason for this stems from the fact that while in B mesons and kaons up type quarks run in the loops, in the charm system down type quarks are contributing to the loops. The phenomenology is in principle the same as for B mixing, but here Γ_{12}/M_{12} is of order one which requires to consider the exact formulas for $\Delta M(M_{12}, \Gamma_{12})$ and for $\Delta\Gamma(M_{12}, \Gamma_{12})$, compared to the approximate ones given in Section 2. While several calculations for the mixing parameters $x = \Delta M/\Gamma$ and $y = \Delta\Gamma/2\Gamma$ exist [32], a satisfactory approach does not exist yet [33]. One of the main difficulties comes from the fact that the short-range contribution to D mixing is strongly suppressed by the GIM mechanism combined with a strong Cabbibo suppression of the b quark in the loop, while long range contributions might be sizeable. While precise predictions are difficult, x and y up to order of 1% are not excluded in the standard model.

Charm mixing poses also difficulties on the experimental side despite huge samples collected by the experiments. In fact while D^0 mixing is established with more than 10σ significance, no single measurement above 5σ exists. Difficulties come from very slow mixing, when the majority of the produced D^0 mesons decay before having a significant chance to oscillate, and a rather small decay width difference, which require extremely good control over systematic effects in order to establish a significant difference. More details of the current results and experimental status are discussed by Malde [9] and Meadows [34].

Since quite some time large CP violation in the charm sector has been considered as a smoking gun for new physics. Independent of the type of CP violation, thanks to the large Cabbibo suppression of the b-quark contribution in charm processes it is almost impossible to generate large CP violation in the standard model. Different authors put their upper bounds to slightly different values, but a general consensus is that CP violation in the charm sector can be at most few times 10^{-3} in the standard model. So if CP violation of a few percent is measured by the experiments it would provide a clear signal of new physics. Several experimental searches for CP violation exist, but up to now no significant effect is seen, neither for mixing induced nor for direct CP violation. For direct CP violation, the most precise experimental

information exists for decays of D^0 to two charged pions or kaons. The world average asymmetries are $A_{CP}(\pi^+\pi^-) = 0.002\pm0.04$ and $A_{CP}(K^+K^-) = -0.0017\pm0.0031$ [6]. A couple of weeks after the conference, a new measurement by CDF was released with $A_{CP}(\pi^+\pi^-) = 0.0022\pm0.0026$ [35], which will further improve the world average. It is worth noting that in $\pi^+\pi^-$ and K^+K^- final states experiments now enter the region where the standard model explanation cannot be excluded even if CP violation is observed.

It should be noted that despite the difficulties in the calculations, D mixing already provides strong bounds on some new physics models. The sensitivity reaches up to scales of 10^2–10^3 TeV in a case of natural couplings, or indicates suppressed couplings in case of new physics at 1 TeV scale, see e.g [33, 36].

While current experiments analysed almost all their data, with LHCb and future B-factories there are good prospects for further improvements. With just a couple of months of physics running the LHCb experiment could clearly demonstrate their capability of collecting charm samples [37]. One of the first public results measuring charm hadron cross-sections shows good agreement with theory and demonstrates the capabilities of the experiment [37]. Signals of many D meson decay modes were already established. As an example with only $124\,\mathrm{nb}^{-1}$ a signal of about 680 $D^{*+} \to D^0\pi^+$ with $D^0 \to K_s\pi^+\pi^-$ is established. The main unknown for LHCb is the question how well the systematic uncertainties can be controlled and how much triggers will be suppressed with increasing luminosity. We refer the reader to Ref. [37] for more information.

It should be also noted that measurements of charm mixing in different decay modes do not provide directly x and y but their linear combinations determined by the strong phase involved in process. The strong phase itself can be extracted in experiments at $D\bar{D}$ threshold like CLEO-c or BES III. Without those experiments future improvements in D mixing will soon become limited without real benefit of a huge statistics from LHCb or future B-factories [34].

6 Conclusions

In summary good progress in B, D mixing, lifetimes and the determination of the V_{tx} elements of the CKM matrix has been made. Many new results are available and especially the ones in the B_s sector cause excitement in the community. While the current generation of experiments comes to the end a lot of useful data is still to be analysed. LHC has started its operation with all LHC experiments including LHCb clearly demonstrating their capabilities and readiness for physics. This together with positive decisions on the future generation e^+e^- B-factories provides bright prospects for the future on the experimental side. On the theory side a large community works on the topics discussed here with gradual progress on all fronts including hard work

towards more precise predictions within the standard model. Altogether the authors see great prospects for a lot of progress over the next two years and expect exciting sessions at the next CKM workshop.

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